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Action Planning for Improvement of Design and Operating Parameters of Ball-Bearing Steel Tube Annealing

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Abstract. Annealing process was reviewed for hot rolled 100Cr6 steel tubes in a chamber furnace with subhearth burners. Based on the obtained results of thermotechnical testing at the chamber furnace it was detected that the current annealing curve conceptually do not allow production of satisfactory quality tube in the course of annealing. As a result an adjusted curve corresponding to the annealing requirements for 100Cr6 steel and chamber furnace capabilities was proposed. Causes were determined for poor quality tube annealing and detailed review was carried out for chamber furnace capabilities in terms of required heat treatment duration ensuring sufficiently high quality of annealed tubes. List of actions allowing significant improvement of chamber furnace performance and annealed tube quality was considered. Chamber furnace renovation option was proposed where the total heat treatment time of tubes may be reduced significantly through heat transfer process intensification in the furnace working space, uniformity of tube heating in the batch, annealing quality and therefore furnace performance may be improved.

1. Tube Annealing Process

Annealing is usually used to relief internal stresses, improve metal mechanical properties and machinability, reduce hardness and prepare the structure for further heat treatment [1–14].

The article deals with the issues related to the annealing process review for 100Cr6 steel tubes in one of the chamber furnaces with subhearth gas burners of Pervouralsk Novotrubny Plant (PNTZ) and recommendations development to allow the treated tube quality improvement.

The furnace is intended for high temperature annealing called in practice annealing to granular perlite [15–19]. Requirements for annealed 100Cr6 steel microstructure and hardness are defined by GOST 801–78. The fuel in this furnace is burnt outside the working space in special fireboxes located under the furnace hearth.

The furnace has the following working space dimensions: length – 9550 mm; width – 2700 mm; height – 1460 mm. Number of gas burners – 11. The furnace is heated with natural gas with combustion heat of kJ/m³. The maximum tube heating temperature is 900°C. With a special vehicle the batch is loaded into the furnace and unloaded from it after annealing. Number of tubes in the batch and their weight depend on the batch length, tube diameter and wall thickness. The batch weight may vary from 10 to 20 t.

100Cr6 steel tube annealing process consists of the batch heating to the temperature of 790 °C and subsequent cooling. Heating and cooling conditions in the course of annealing are determined by the annealing curve shown in the instruction for tube heat treatment. Temperature in the furnace working



space is checked by three roof chromel alumel thermocouples, located 100–150 mm above the annealed tube batch. Temperature inside the batch in the course of tube annealing is measured by a side-mounted thermocouple inserted through a furnace wall hole located at the distance of 4.5 m from the furnace front face. Side-mounted thermocouple is installed between the first and second tube layers at a three layer batch and between the second and the third layers if number of layers in the batch is four or more. Thermocouple readings are registered automatically by a potentiometer recorder with the scale of 400 to 900 °C. Annealed tube length is 6–8 m, and diameter is 60–160 mm.

Annealing quality is checked by two methods. About 10 % of all annealed tubes in the batch are inspected on a coercimeter where annealed steel hardness is checked. Samples are taken from reference tube front ends for laboratory microstructure and hardness analysis. Steel with the structure of 1–4 according to scale no. 5 and Brinell hardness of 179–207 what complies to the impression diameter of 4.2–4.5 mm is considered acceptable.

2. Experimental

Testing was focused on research of tube annealing conditions in the furnace central portion where heat treatment conditions are something like that at which the furnace and the batch may be considered as infinitely long. The experience shows that such conditions are met in the furnace portion beginning at the distance of 0,6 m farther the tube front ends and ends at the same distance nearer the rear ends.

The first stage of thermotechnical testing at the chamber furnace was related to regularity study of the temperature conditions for the batch tube annealing. The major method of required information gaining at that was temperature measurement in the selected points of the annealed tube batch using chromel-alumel thermocouples. Temperature distribution was examined throughout the batch length, width and height as well as in the batch cross section vertically and horizontally. The second stage was related to determination of the batch tube optimal heating time at the recommended temperatures ensuring the required annealed tube quality.

The work program provides for action plan development intended for chamber furnace performance improvement. At this investigation stage some conclusions with regard to causes of annealed tube quality deterioration and plans for their elimination became possible. Certain constructive proposals are available for furnace capacity increase. Actions proposed below for tube annealing quality and capacity improvement in the chamber furnace result from the thermotechnical testing and review of chamber furnace capabilities at the current annealing process. These actions may be divided in two groups: those that do not require and those that require revamping of the current equipment.

Actions from the first group require no additional costs or time and may be implemented immediately. Actions from the second group require additional costs, model research, practical development, etc. and may be considered as a plan for further work.

Let's consider actions requiring no revamping of the current equipment. The proposed actions result from the need to adjust the current annealing curve and quality inspection procedure. Review of high quality annealing capabilities for 100Cr6 steel tubes according to the current curve is considered above. Evidence obtained from the experiments demonstrates that the current curve conceptually does not allow obtaining of sufficient annealing quality because of the batch bottom tube underheating.

As experience shows the tube batch section may be divided into three zones (figure 1) with regard to tube heating adequacy in these zones as per annealing temperature condition requirements of 100Cr6 steel. In the first zone standard tube heating is ensured, however it is somewhat more lengthy than required on the batch outside. In the second zone the tubes are underheated although slightly. In the third zone the tubes are significantly underheated what causes annealed tube unacceptability both with regard to microstructure and hardness. The stated deficiency of annealing may be currently avoided only by one method: temperature increase for bottom tubes minimum to 780°C and their holding at this temperature for at least two hours. Increase of total annealing time at that may be partially or completely offset by increased heating and cooling intensity. Current heating temperature margin comprises 25–30 °C. Maximum heating temperature according to the roof thermocouple in the

instruction is 810°C. At that the observed maximum temperature on the tube surface is 815–820 °C. Therefore, heating may be carried out at the temperatures of 820–830°C, without fear of overheating as at that the tube surface temperature will be no higher than 835–840°C. Such temperatures of up to 840–850°C are not dangerous with regard to overheating [15]. Thus in one of the experiments the heating temperature was within 825–850°C, sample time in the furnace was four to seven hours. Sample cooling rate equaled 20–30°C/h. Out of six annealed samples no reject was detected. Hardness measurements gave impression diameter of 4.2–4.3 mm. At that samples with the impression of 4.3 were cooled more slowly. No impact was detected for hardness from heating time and rate. Only in case of very massive batches overheating structure may be expected due to lateral tubes held at the temperatures of 820–830 °C, generally not dangerous with regard to overheating, for too long. In such cases heating shall be carried out in two stages, first at the temperature of no higher than 800 °C, and at the temperature of 820 °C at the end. Cases when such complication and additional procedure extension is necessary may be determined only by direct experiments.

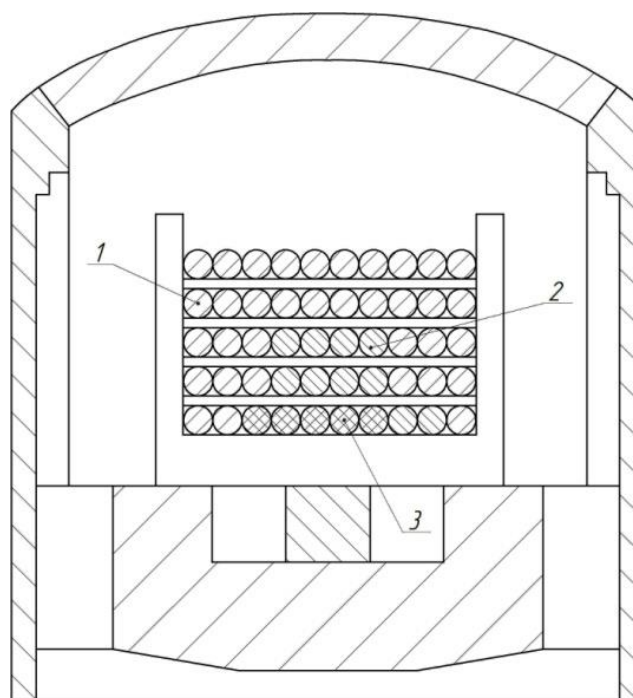


Figure 1. Various tube heating zones of batch cross section: 1 – standard heating zone; 2 – slight underheating zone; 3 – significant underheating zone.

As to cooling it may also be slightly more intensive than in current practice. Cooling rate monitoring is the most complicated. Roof thermocouple readings can give approximate information on the cooling rate. As experience shows roof thermocouple readings decrease about twofold slower as compared to the lateral tube surface temperature. As tube cooling rate shall not exceed 30–60 °C/h, temperature reduction rate according to the roof thermocouple shall not exceed 15–30 °C/h. Practically the risk of too rapid cooling is eliminated if the temperature reduction rate according to the roof thermocouple is 10–20 °C/h. At that initial shock cooling shall not be below 740 °C, and subsequent cooling is preferable with approximately the same intensity ensuring decreased readings of the roof thermocouple with the rate of 10–20 °C/h. It is expedient to reduce breaks in air supply for temperature equalization to 30 minutes and to increase air supply periods to 1.0–1.5 hours (currently the time ratio is reverse). Annealing curve inclusive of all proposed changes is shown in figure 2. It is broken into three intervals: heating, equalizing and cooling. Heating is proposed with the same intensity to the temperature of 800 °C according to the side-mounted thermocouple. Then the burners

are turned off and equalizing lasts for 1.5–2.0 hours, during which the temperature in the batch equalizes to the level of 790–800 °C. The last stage – cooling begins from the batch sudden air purging to the temperature of 740 °C according to the roof thermocouple. Then uniform, significantly less intensive cooling with the rate of 10–20 °C/h according to the roof thermocouple continues with intermittent breaks in cooling air supply. At that it shall be considered that more intensive annealing increases requirements to temperature monitoring accuracy in the furnace.

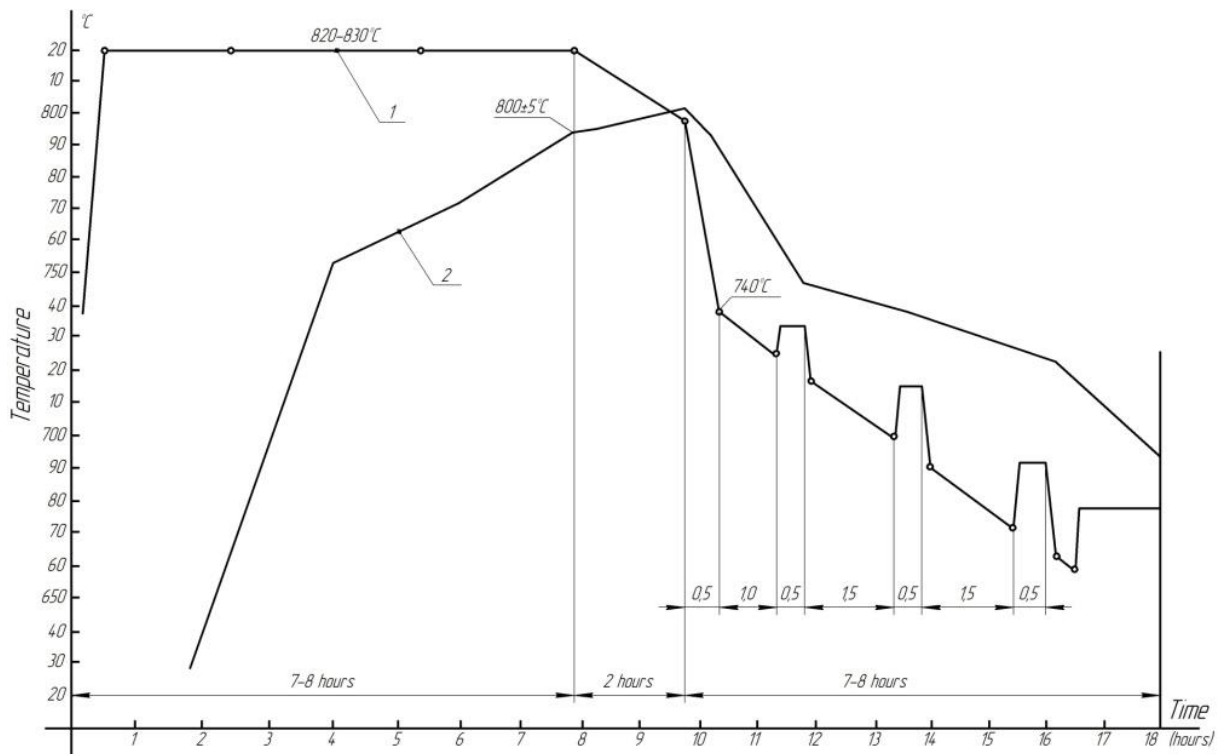


Figure 2. Recommended annealing curve for 100Cr6 steel tubes: 1 – roof thermocouple curve; 2 – side-mounted thermocouple curve.

Currently (as noted above) annealing quality is inspected by two methods complementing each other: tube hardness inspection on a coercimeter and laboratory microstructure and hardness inspection of samples. Disadvantage of the current inspection procedure is its one-sidedness. It is due to the sampling procedure of reference tubes in the annealed lot and specimen cut out only from the tube front ends. At that underheating of batch bottom tubes is neglected. To make inspection a more efficient method of annealing quality improvement it is suggested that two top lateral tubes of the batch and two middle tubes of the bottom layer shall be taken for inspection (figure 3). Specimens from the top tubes shall be cut from front ends and from the bottom tubes – at the distance of 0.9–1.0 m from the tube ends. With such sampling procedure batch tube underheating and overheating are not neglected.

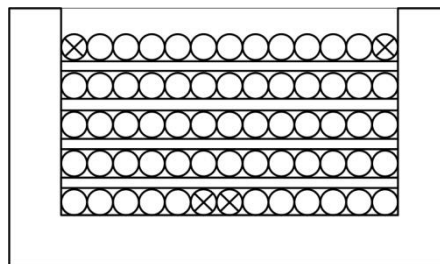


Figure 3. Proposed reference tube sampling procedure, ⊗ – reference tube.

The idea of the current furnace revamping is of interest. To increase the convective heat transfer rate between the heating gasses and the batch it is suggested that fans shall be installed in the furnace rear part to ensure intensive gas blending throughout the furnace volume [20]. Heating gasses drawn in from the furnace with the fan through a special gas duct (i.e. formed by a double roof) are fed into the furnace front part. Thus a closed loop is created for heating gas circulation. In case of long-term circulation some gasses draw through the tubes and ensure heating of each tube from two sides – from outside and from inside. Rough estimates show that at that annealing time reduction by 4–5 hours may be expected. Together with the heat transfer process acceleration the tube heating (cooling) uniformity and therefore annealing quality improves. At that tubes may be placed on the cross beams without spacers, and therefore tube distortion may be avoided.

With quite good gas blending with an additional fan the need for very accurate maintaining of steady operation of separate burners disappears and fuel burning process may be controlled via a grandmaster. Besides the temperature monitoring may be significantly simplified and reduced to the temperature inspection in one representative point. Overall annealing process automation conditions improve significantly as control with one gate valve based on one thermocouple readings presents no challenge.

Besides the proposals considered above some other proposals are also of interest. For example, cooling air injection into the furnace not only from the bottom but also from the top. With the corresponding design this would ensure significantly better blending and more homogeneous cooling. It makes sense to preheat cooling air with the flue gas heat, etc. It is only necessary to confirm every time the expedience of changes introduced into the furnace design with the corresponding testing.

3. Summary

The results of the annealing process investigation for 100Cr6 steel tubes in a chamber furnace obtained in the work are of certain interest for specialists dealing with steel heat treatment. Tube annealing curve adjusted according to the requirements for 100Cr6 steel annealing conditions allow as distinct from the current one reasonable choice of the required heating, holding and cooling time of the tube batch at the corresponding temperatures and assurance of steel production with the required hardness and microstructure properties. The proposed furnace revamping allowing tube heating in the batch from two sides undoubtedly will contribute to annealed tube quality and furnace performance improvement.

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